Optical characteristics of the Marshall Space Flight Center Solar Ultraviolet Magnetograph

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ABSTRACT

This paper will describe the scientific objectives of the Marshall Space Flight Center (MSFC) Solar Ultraviolet Magnetograph Investigation (SUMI) and the optical components that have been developed to meet those objectives. In order to test the scientific feasibility of measuring magnetic fields in the UV, a sounding rocket payload is being developed. This paper will discuss: (1) the scientific measurements that will be made by the SUMI sounding rocket program, (2) how the optics have been optimized for simultaneous measurements of two magnetic lines CIV (1550 Å) and MgII (2800 Å), and (3) the optical, reflectance, transmission and polarization measurements that have been made on the SUMI telescope mirrors and polarimeter.

1. INTRODUCTION

A major focus of solar physics is the measurement of the temporal and spatial variability of solar magnetic fields from the photosphere into the lower corona, and determining how this variability produces the dynamic phenomena in this region of the solar atmosphere. Some success has been achieved in the characterization of the full vector field in the photosphere, where β, the ratio of the gas pressure to the magnetic pressure, is ≥ 1. But at higher levels in the atmosphere (Figure 1)[1] where $\beta \ll 1$, the magnetic field (through the Lorentz force) controls the structure and dynamics of the solar atmosphere, and rapid changes in its structure can produce energetic events. However, observations of the magnetic field at these higher levels have proven to be extremely difficult, placing a serious limitation on our understanding of the physical processes actually occurring there. This paper will discuss the Solar Ultraviolet Magnetograph Investigation (SUMI) polarimeter that has been designed to measure the polarization in the ultraviolet lines of CIV and MgII which are formed in the transition region and upper chromosphere. We are currently developing this polarimeter and other optical technologies required to build an instrument that will achieve a major advance in the measurement of magnetic fields in this wavelength region. Initially configured as a sounding rocket payload, such a UV magnetograph would allow us to make exploratory measurements extending the observation of solar magnetic fields into new and dynamic regimes.

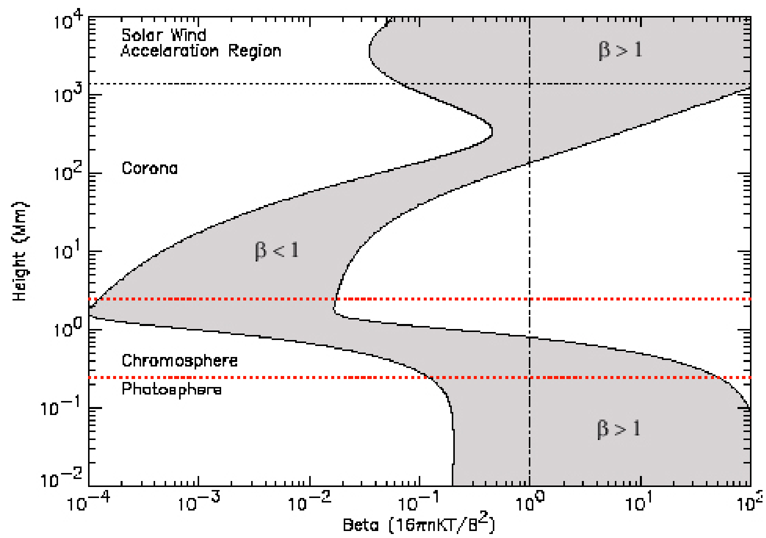

Figure 1. Ratio of gas pressure to magnetic pressure (β) as a function of height[1].

2. SCIENTIFIC RATIONALE

A primary goal of NASA's Sun-Earth Connection Program (SEC) and the Living With a Star initiative (LWS) is to develop an ability to predict when a stressed magnetic active region is about to undergo an explosive event that launches a coronal mass ejection (CME). *Yohkoh* coronal X-ray images have shown that CME explosions are more likely to occur in regions having sigmoidal coronal magnetic fields than in regions with less contorted field configurations. The degree to which the contorted fields depart from a potential configuration represents the free magnetic energy content of the region and is evidently a good indicator of whether a region will produce CMEs. This qualitative lead should be pursued. The free magnetic energy content of a region can be estimated from integrals over vector magnetograms, but accuracy depends on the fields being measured at a sufficient height in the atmosphere for them to be very nearly force free.

Also, the force-free fields in the transition region and corona may undergo large changes in direction without measurable change in the photospheric roots. So, to follow the evolution of the 3D force-free field (both for CME studies and for more general purposes), the vector magnetograms from which the field is extrapolated must be obtained from a force-free layer. Therefore, to meet the goals of SEC and LWS, measurements of the vector magnetic field in the middle to upper chromosphere and/or lower transition region are needed (See Figure 1). The ultraviolet spectrum is rich in magnetically-sensitive strong emission lines that are formed at various temperatures throughout the chromosphere, transition region and low corona. Our approach to achieve the measurements of the vector field in the low- β regions of the solar atmosphere is to develop a vector magnetograph that measures the polarization in one or more of these lines. Such an instrument would be a crucial complement to all visible-light magnetographs, on ground or in space, both in an attempt at forecasting CMEs and in the more general problem of determining the 3D structure and evolution of the coronal magnetic field.

For the desired sensitivity to the Zeeman effect, the lines should have steep wings, low adjacent continuum intensity, and a simple Zeeman pattern. To obtain accurate measurements of the magnetic field in this region, SUMI will use two pairs of lines having complementary characteristics. The first pair (MgII) is formed in a narrow region and is optically thick, thus avoiding line of sight superposition uncertainties. A second pair (CIV), although optically thin, is still formed in a fairly narrow range of heights and provides a particularly simple emission line profile for analysis. Lande g factors, an indication of the magnetic splitting, for both pairs of lines are ~1.2.

The profiles of the MgII *h* and *k* lines at 2795 Å and 2803 Å show broad, deep absorption that is formed in a layer containing the upper photosphere and low chromosphere. Although the absorption components of these lines have a weak polarization due to resonant scattering[2], this polarization is not very useful because of the small slope of the absorption profile. Instead, the line core, which shows a large central emission that is reversed in the quiet Sun but not in sunspots, can be used in magnetic field measurements[3]. The emission in this spectral range is formed in a narrow range of temperatures at the top of the chromosphere[4]. The line formation processes for these lines are similar to those for the CaII *H* and *K* lines. The main difference in the CaII lines and the MgII lines is that the CaII lines show only small emission cores and are formed lower in the solar atmosphere. The emission cores of the MgII lines have a very sharp rise and a good contrast with respect to the weak intensity at nearby wavelengths. These line cores form in a relatively small range of altitudes (~300 km in extent) near the top of the chromosphere, well separated from the levels where the optical lines are formed. For these reasons, this pair of lines is ideally suited for studies of the magnetic field at the top of the chromosphere.

In the vacuum UV, the CIV (2s-2p) lines, at 1548.2 Å and 1550.8 Å, are observed to have simple emission profiles that are formed ~200 km higher than the MgII lines and at a temperature of ~10^5 K. Although these lines are more straightforward to analyze, they lie deeper in the UV making them more difficult to observe. However, this is taken into consideration in developing the SUMI technology (Section 3).

3. SUMI SOUNDING ROCKET PROGRAM

The current focus of the SUMI program is to develop the optical technologies that will allow us to build a UV solar vector magnetograph to make exploratory measurements of the currently unobservable magnetic fields in the transition region and upper chromosphere. Specifically the program is developing materials and coatings to extend the operating range of standard optical components to work in the vacuum UV The objective is to make polarization images of the Sun at wavelengths of 1550 Å and 2800 Å.

In this program we are:

- Developing the UV cold mirror technology required to reduce the thermal load on a solar-observing UV magnetograph. The durability, thermal characteristics and aging properties of the UV cold mirror coatings will be tested.
- Optimizing the polarizing optics for simultaneous observations of the MgII and CIV emission lines.
- Developing a double Wollaston UV analyzer which will allow simultaneous observations of orthogonal polarizations for each emission line.

- Developing a spectrograph with a spherical-variable-line-spacing (SVLS) grating that can achieve a spectral resolution of 33mÅ at CIV.
- Developing a UV Fabry Perot etalon that will be used with a slit jaw camera to isolate the CIV/MgII lines and generate a field of view map for the spectrograph observations.

This paper will describe the progress that has been made in the development of the telescope and polarizing optics for the SUMI sounding rocket program. Since the polarization resolution in this wavelength band is limited by the photon statistics, this paper will concentrate on the efficiency of the optics and the improvements that have been made since the flight of the Ultraviolet Spectrometer and Polarimeter (UVSP)[5] on the Solar Maximum Mission (SMM). The UVSP was the first scientific instrument to attempt polarization measurements in the UV. Since these were exploratory measurements, the UVSP polarimeter design was “broad-band”. In order to decrease the photon noise that limited the UVSP polarization resolution, the SUMI magnetograph is concentrating on improving the overall efficiency at two of the magnetically sensitive lines in this wavelength region. The SUMI polarimeter and its polarization characteristics are described elsewhere[5]. While the SUMI sounding rocket program is designed to prove the concept of a UV magnetograph, the ultimate goal of this program is to develop an instrument for an Explorer Mission that will complement the visible light/photospheric magnetograph observations of the Japanese Solar-B Mission and the Solar Dynamics Observatory planned under the LWS. Using these observatories, solar scientists will finally be able to study the three dimensional, dynamic evolution of solar magnetic fields and their influence on solar activity.

3.1 BASELINE DESIGN OF SUMI TELESCOPE

The solar telescope design must solve the thermal problems associated with direct solar viewing. The easiest solution is to use a Gregorian design (Figure 2) with a field stop between the primary and secondary mirrors. While this restricts the field of view, it reduces the thermal load on the secondary by reflecting the unwanted light from the region outside of the aperture stop. The disadvantages of this design are a limited field of view, a longer optical path, and a larger secondary, which decreases the collecting area of the telescope. The SUMI approach for decreasing the thermal load on the secondary mirror is to use a Ritchey-Chretien telescope design (Figure 3) with special dielectric coatings, applied to the front surfaces of both the primary and secondary mirrors. These coatings (Section 4.2.1) will only reflect narrow wavelength ranges which results in a "cold mirror", i.e., a "self-filtering" telescope. The rear surface of the primary mirror is figured and has a broadband coating that reflects the unwanted radiation back through the telescope. The advantages of this design are that the field of view is not restricted (so the whole Sun could be imaged) and, for a given instrument length, the smaller telescope size will allow an increase in the length of the spectrograph arm, thus improving the wavelength resolution. With these narrowband UV reflection coatings on the primary and secondary mirrors, we will simplify the thermal environment, minimize infrared and visible light contamination of the spectral data, and simplify the spectrograph design.

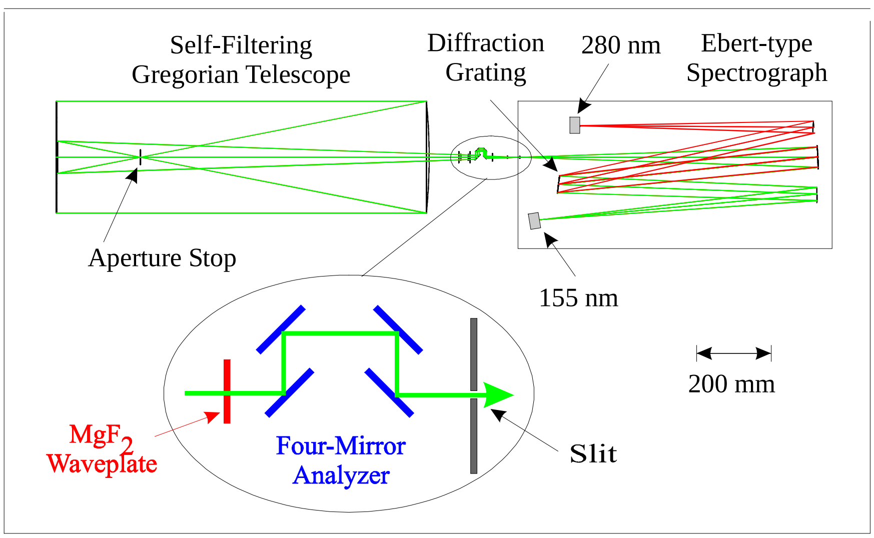

Figure 2 Initial baseline design of SUMI using the UVSP as its model

Although the dielectric coatings on the SUMI telescope are an important element of the design, three other areas have also been optimized to improve SUMI’s overall optical efficiency for measurements at CIV and MgII: (1) the polarization analyzer, (2) waveplate retardance, and (3) reducing the number of reflections in the spectrograph from three (Figure 2) to one by using a spherical-variable-line-spacing (SVLS) grating. We are currently in the design phase for this grating and hope to make reflectance and polarization measurements on that design in the spring of 2002.

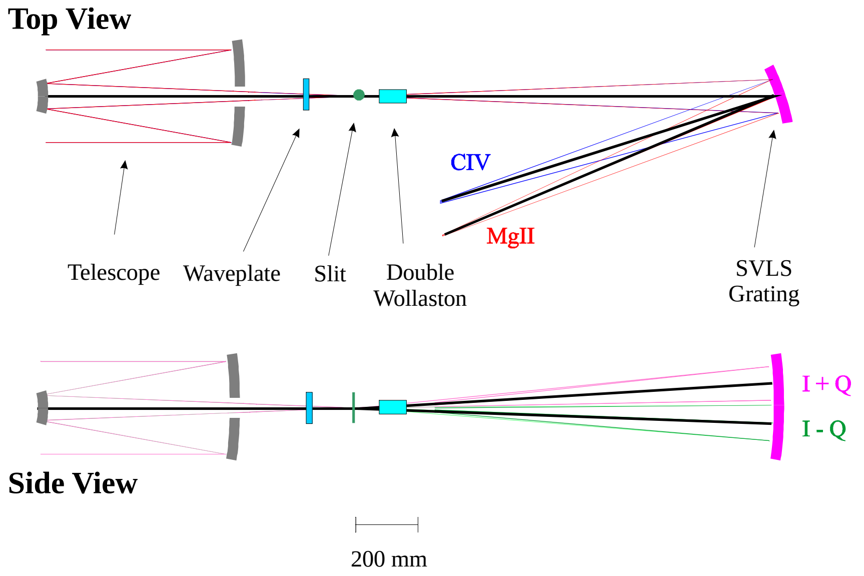

Figure 3. Current optical design of the SUMI SOUNDING ROCKET PROGRAM telescope

3.2 SUMI POLARIMETER

The sounding rocket platform places strong constraints on the scientific program that can be achieved within the observing time. This, coupled with the weak linear polarization signals expected in the CIV emission, forces us to optimize the polarimeter for circular polarization measurements at CIV. The MgII emission is approximately three orders of magnitude larger than CIV so it is expected that both linear and circular polarization measurements will be possible. Although an achromatic quarterwave retarder is still being developed, the baseline design for the UV magnetograph is a first order MgF_2 design shown in Figure 4. In order to estimate the effects of a polarimeter design on the polarization measurements, we define the polarization efficiency to be the square of the polarization detected given a 100% incident polarization. Normally, the detected polarization is simply the difference over the sum of two polarization measurements. In order to obtain a minimum polarization resolution, any loss in the detected polarization would require additional images to recover that information. For example, given a 100% incident polarization, the grating on the UVSP[6] measured 63% polarization signal. Therefore, to achieve the same resolution as a system that could measure a 100% polarization signal, 2.5 images would be required. With a limited observing time, the polarimeter has been optimized to obtain 100% circular polarization signal at CIV. Since the MgII line is much stronger, almost one hundred polarization images can be acquired in the same time required to obtain a single CIV polarization map. Therefore the circular polarization efficiency of the waveplate in Figure 4 is designed to be 100% at CIV while still achieving 74% at MgII. While the polarization efficiency does not affect the exposure time, which is dictated by photon statistics, it does affect the time required to obtain a given polarization resolution.

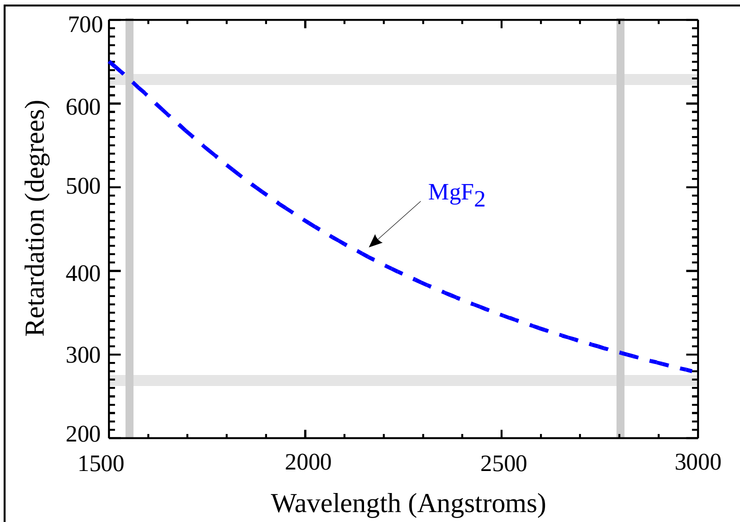

Figure 4. Retardation as a function of wavelength

For waveplates, the polarization efficiency is related to the retardation and the polarization to be measured. For the analyzer, the polarization efficiency is the related to ability to isolate a given polarization. Most analyzers use absorption (polaroids), reflection (mirrors, gratings and some birefringent analyzers) and birefringence to isolate the polarization to be measured. For absorption and reflection analyzers the transmission efficiency can never be greater than 50% and for most UV analyzers it is below 15%. The SUMI analyzer is a double Wollaston which uses the birefringence of MgF_2 to split the incident light into two polarization signals. Therefore, the double Wollaston can have both a high broadband polarization efficiency and a transmission efficiency greater than 50% (Section 4.2).

4. THE SUMI OPTICAL TEST PROGRAM

This section will describe the transmission and reflectance tests that have been performed at the Marshall Space Flight Center UV test facility. Polarization tests are also needed to determine the overall efficiency of the UV magnetograph and the results of these tests are described elsewhere[6]. Section 4.1 will describe the SUMI telescope, its design characteristics and its optical performance. Section 4.2 will describe the VUV test facility, the dielectric mirror reflectance measurements, and the transmission measurements of the SUMI SOUNDING ROCKET PROGRAM polarimeter. Using this data, Section 4.3 will compare the overall efficiency of the current SUMI design with its initial design that was based on the UVSP.

4.1 OPTICAL FABRICATION OF THE SUMI TELESCOPE

The Space Optics Manufacturing Technology Center (SOMTC) at Marshall Space Flight Center (**http://optics.nasa.gov**) is fabricating the SUMI telescope mirrors and specializes in the design, manufacturing, metrology and testing of space optics. The limited observing time of the SUMI sounding rocket program requires a compromise between spatial and polarization resolution. Therefore the design goal of the SUMI telescope is 1 arc second resolution for MgII and 2 arc second resolution for the CIV polarization measurements. Currently, the smallest, commercially available, back-illuminated CCD detector has a pixel size of 13 µm. Therefore, this pixel size was selected for our baseline design. While the spatial resolution for the polarization measurements through the spectrograph is not diffraction-limited, the optical requirement for the SUMI telescope is for diffraction-limited images at MgII for the slit-jaw camera. In the spectrograph arm, the telescope is simply a large light bucket required to improve the photon statistics of the Stokes profiles. The main requirements for the spectrograph arm are (1) low scatter from the polished surfaces of the telescope mirrors, (2) high reflectivity of the CIV and MgII wavelengths, and (3) high rejection of the out-of-band wavelengths

4.1.1 Optical design

In order to increase the field of view, correct for off-axis aberrations, and to reduce the overall length of the telescope, the SUMI optical design uses a Ritchey-Chretien telescope. The primary and secondary of a Ritchey-Chretien are both hyperboloids. This configuration represents an improvement over the optical performance of a conventional Cassegrain telescope, and is more efficient in this application than a Gregorian design (Section 3.1). Special reflective coatings (Section 4.2.1, Figure 8) are required to reduce the thermal load on the secondary mirror and polarimeter optics of the SUMI magnetograph. A dielectric coating is applied to the front surfaces of both the primary and secondary mirrors to reflect only the CIV and MgII wavelength bands. The unwanted visible and infrared wavelengths are transmitted through the primary and secondary mirrors. The back surface of the primary mirror is figured and has an aluminum coating, so that it reflects a collimated beam back out the entrance aperture of the telescope. The back surface of the secondary mirror has an anti-reflection coating. It is followed by an aluminum mirror to reflect the out-of-band wavelengths (~4% from primary mirror) away from the spectrograph optics. To reduce the absorption, fused silica is used in both the primary and secondary mirrors. While dielectric mirrors have been used previously to selectively reflect wavelength bands in solar telescopes, the SUMI telescope requires a unique on-axis, radially symmetric design to minimize the instrumental polarization and to use the full aperture for both wavelength bands. The first set of dielectric coatings that are placed on the telescope mirrors are for the MgII lines (2800 Å). The CIV dielectric stack is then placed on top of the MgII coating. This reduces the absorption loss at CIV that can be expected in any dielectric coating. Table 1 summarizes the design characteristics of the SUMI telescope.

Table 1. Design characteristics of the SUMI telescope

F#	12.387
Effective focal length	3716.037
Primary/secondary distance	606.156 mm
Primary mirror	
Front surface	
Curvature	-1664.320
Conic	-1.036946
Coating	Dielectric: CIV and MgII
Back surface	
Curvature	-7150.000
Conic	0.000
Coating	Aluminum
Secondary mirror	
Front surface	
Curvature	-580.738
Conic	-2.779264
Coating	Dielectric: CIV and MgII
Back surface	
Curvature	None

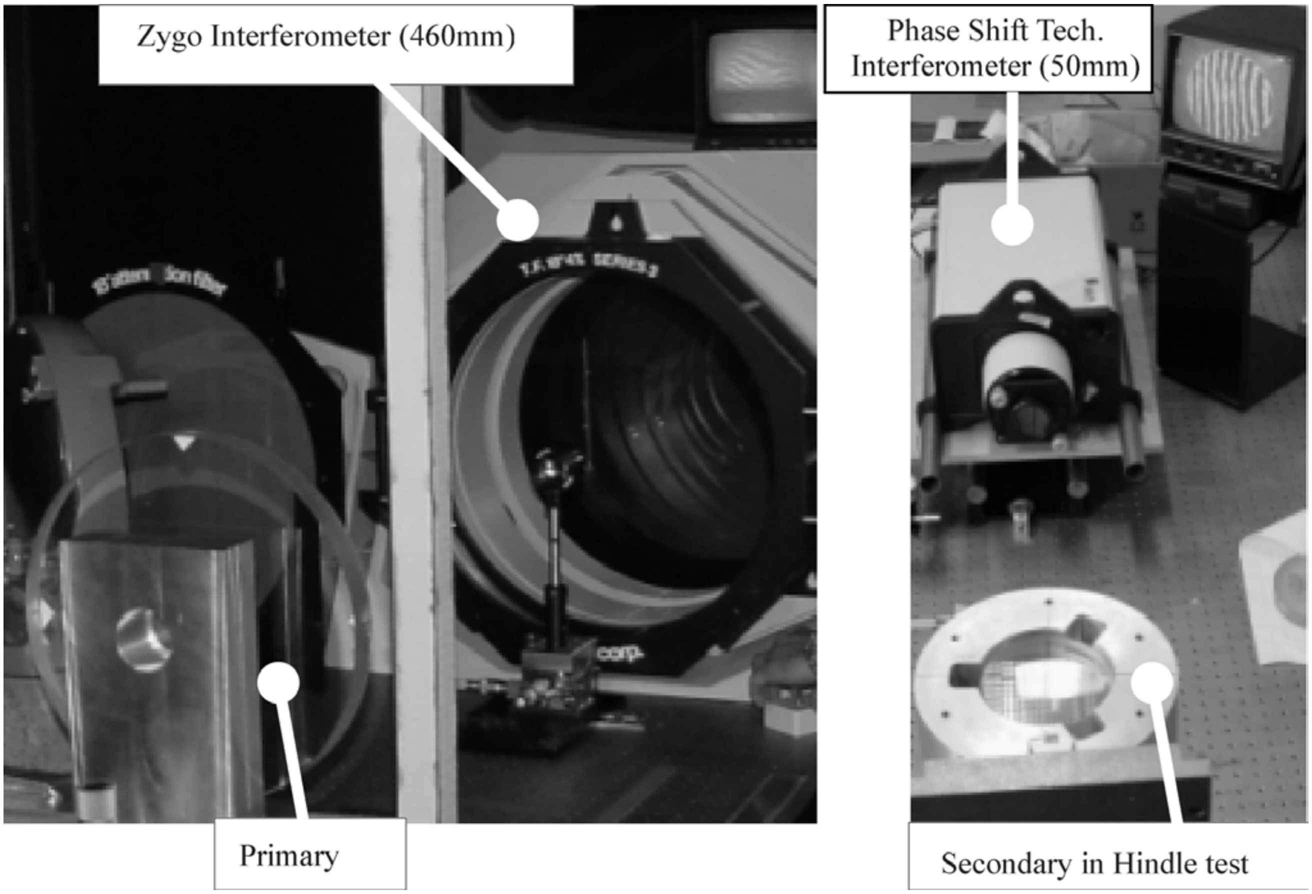

Figure 5 Primary and secondary mirrors in interferometer test setups to measure surface finish and profiles.

4.1.2 Optical testing of SUMI mirrors

While the dielectric coating solves the thermal issues of observing the Sun, it is difficult to test the telescope as a system using conventional techniques. Using a Zygo interferometer to characterize the telescope mirrors after the dielectric coatings have been applied is not possible since the reflection of HeNe wavelengths is below 0.2% in a single pass through the telescope. Therefore, the optical testing of the telescope mirrors has been split into three steps. In the first step the secondary is evaluated with a Phase Shift Mini Fiz interferometer, the primary is evaluated with a Zygo interferometer and the system performance is determined using Code V. In this step the secondary mirror is flash coated with aluminum, set up in a Simpson-Oland-Meckel-modifed Hindel test[7]. and the performance of the mirror measured at HeNe. The SUMI secondary mirror had over 80 flash coating runs where the Strehl, RMS figure and RMS wavefront have been measured, and used to generate "hit" maps of the mirror. These maps were then used in the final polishing so that diffraction-limited performance at MgII could be achieved. Also in this step the primary mirror is tested, uncoated, against a 0.4m collimated output beam from a Zygo interferometer in autocollimation with a small concave sphere used as a retrosphere beyond focus. Since the autocollimation test is a null test for a parabola a file containing the differences to the desired hyperbola is subtracted from the test results using the Zygo software. This test is used since the required hyperbola for the primary mirror is very nearly a parabola and the difference subtracted using software is less than 1.0 wave at the HeNe wavelength of test. Code 5 is then used to combine the results of the independent primary and secondary mirror tests to "simulate" the system and convert this result to the CIV and MgII wavelengths. The second step in the optical testing is to measure the reflection characteristics of the dielectric coatings. This is describe in Section 4.2. After the telescope mirrors are coated, the final step is to align the telescope to its best focus, perform a knife edge test and then measure the point spread function of the telescope. The telescope will then be placed in the SUMI Vacuum Ultraviolet (VUV) test facility for its final checkout and documentation.

4.2 TRANSMISSION AND REFLECTANCE TESTS

The SUMI VUV spectrophotometric test facility (Figure 6) has been developed at the NSSTC/MSFC for measuring the optical properties (transmittance, reflectance and polarization) of test samples in the wavelength range from 1150 Å through the visible. This facility was used to test the Ultraviolet Imager for the International Solar Terrestrial Physics Mission and for the Wide Imaging Camera for the IMAGE Mission. For VUV optics, contamination is a serious concern. In order to minimize exposure of test optics to contamination, the spectrophotometric system is maintained in a class 1000 clean area in a stainless steel vacuum chamber. A cryogenic hydrocarbon-free pumping system is used to avoid contamination. The vacuum system operates with a base pressure in the 10^{-7} torr range. For FUV measurements, a high-pressure arc discharge deuterium lamp is used as the source. This source has a continuum output in the 1150 Å –3700 Å range, and is used to scan the transmission, reflection and polarization characteristics of the SUMI optics. A 0.2m vacuum monochromator, with a concave holographic grating (1200 lines/mm) coupled to a 76.2cm focal length collimating UV enhanced mirror system, produces a 10.2cm monochromatic collimated incident beam. Two vacuum compatible linear stages and two rotational stages are used to position the detectors, optical components and test samples during the calibration and testing process.

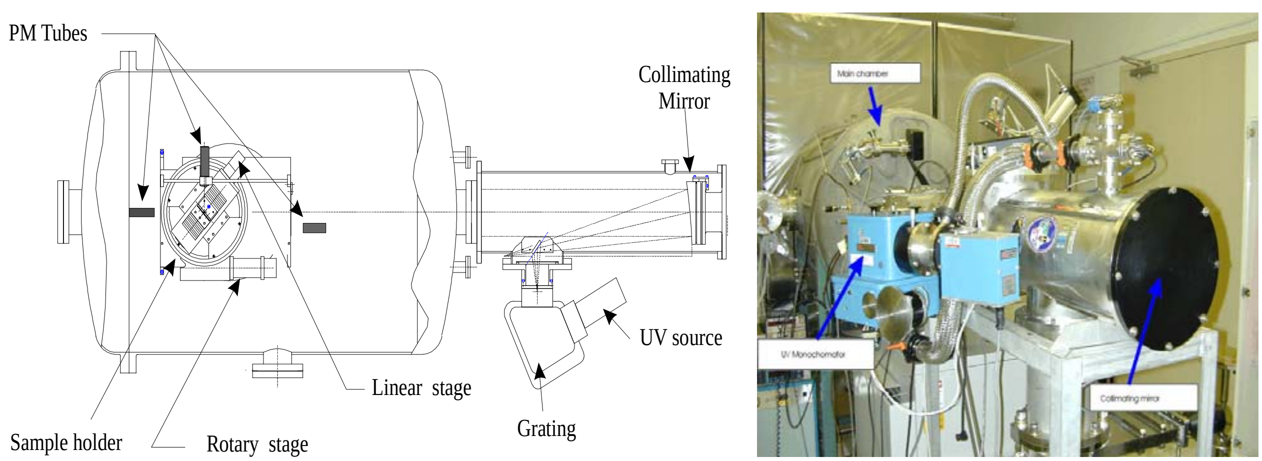

FIGURE 6 SUMI TEST CHAMBER

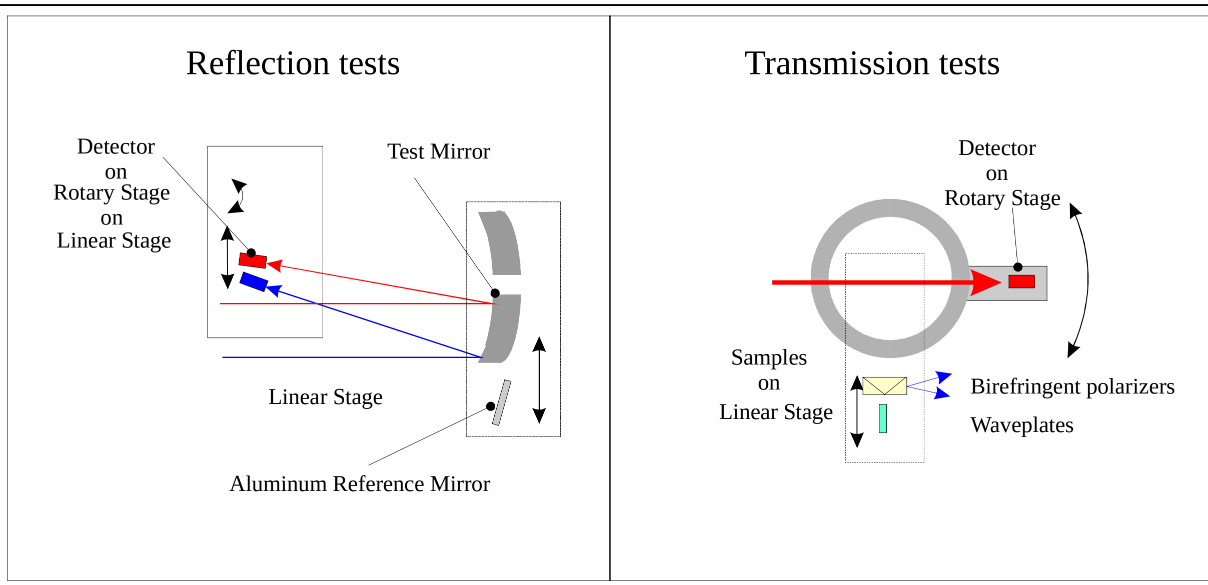

Figure 7. Test setups for reflectance and transmission measurements on SUMI optics

Problems in measuring the “absolute” transmission and reflectance of the SUMI optics have been associated with the instrumental polarization from the grating and fold mirrors in the monochromator, and with small misalignments of the detector when making source and sample measurements. Therefore the test setups described below try to minimize these effects in order to reduce the systematic errors in the transmission and reflectance measurements.

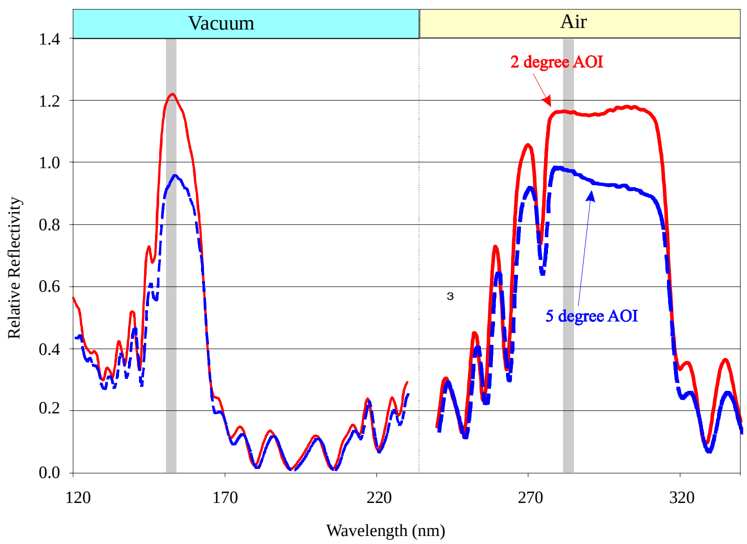

Figure 8. Relative Reflectance measurements on SUMI dielectric coatings

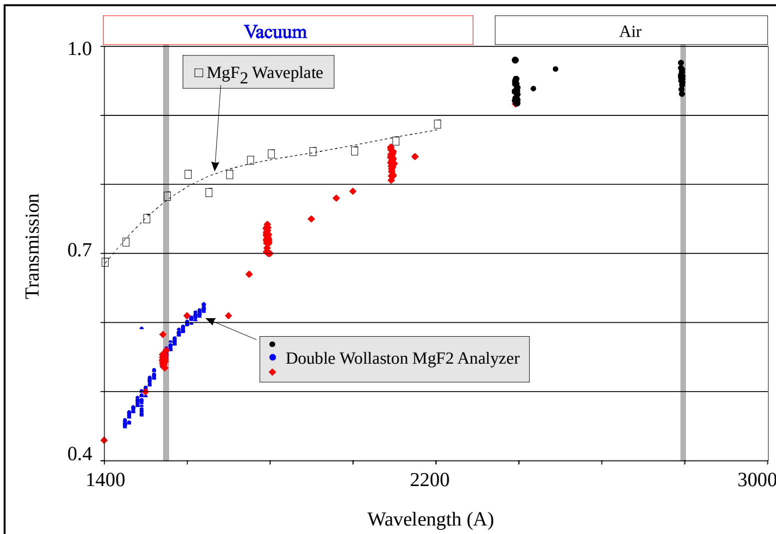

Figure 9 Transmission measurements on the SUMI sounding rocket program double Wollaston analyzer and waveplate

Figure 7 shows the test setups for the transmission and reflectance tests. Of the two tests, the reflectance test of the telescope mirrors presents the most difficulties in minimizing the instrumental errors. This is due to the large differences in the optical path length between the source and mirror measurements. The same detector that measures the signal from the mirrors must be rotated 180 degrees and inserted into the beam to monitor the source. Therefore the optical path length for the mirror measurements is ~2100 mm while the source path is ~10 mm. The long optical path in the mirror measurements is required in order to measure the small angles of incidence of the telescope mirrors (~1.5 to 5 degrees). A small tilt or height misalignment of the mirror path and the source path produces a systematic error. Therefore the reflectance measurements of the dielectric mirrors are all relative to an uncoated aluminum reference mirror set to the same angle of incidence. Figure 8 shows the UV reflectance tests of the SUMI dielectric coatings at two angles of incidence.

In the transmission tests the optical path is the same for the source and sample measurements so the tilt and height errors are small. The systematic error in these tests is associated with the instrumental polarization created by the fold optics in the monochromator. This error is minimized in the double Wollaston transmission tests since the signal level of both polarizations exiting the polarizer are measured. The double Wollaston is then removed and the signal from the source is measured. Since the detector is mounted on a large rotary stage and the double Wollaston is mounted onto a linear stage which is placed at the center of the rotary stage, the optical paths are the same. Therefore the detector will see the “same” polarization minus the absorption and reflection losses within the analyzer. For the waveplate transmission measurements, the fast axis is aligned to the “transmission” axis of the monochromator optics. In this case the waveplate does not change the incident polarization and the detector sees the same polarization no matter if the waveplate is in or out of the beam. Figure 9 shows the transmission measurements of the polarization optics that are part of the SUMI polarimeter.

4.3 OPTICAL EFFICIENCY OF SUMI DESIGN

During the development of the SUMI program, the initial design concepts concentrated on improving the UVSP design , which was the only known instrument that had tried to make polarization measurements in this wavelength region. Certainly those measurements were limited by the photon statistics (or radiometry) and the polarization resolution of the instrument. The initial SUMI design (Figure 2) copied the UVSP polarimeter and spectrograph but increased the collecting area, and proposed to improve the reflectivity of the telescope optics and optimize the polarimeter for CIV measurements. The polarimeter improvements would be accomplished by adjusting the retardance of the waveplate and by optimizing the reflectivity of the four mirror analyzer for CIV. The current SUMI sounding rocket program design improves on that initial

Table 2. Comparison of initial SUMI design estimates with measurements made on SUMI optical components

Optical Design Parameters	***Initial SUMI design:*** **Estimates**	***SUMI SOUNDING ROCKET PROGRAM design:*** **Measurements**
Telescope collecting area[a]	628 (cm^2)	646 (cm^2)
Telescope coating		
reflectance at 1550 Å	0.71	0.86[b]
reflectance at 2800 Å	0.82	0.99 [b]
Waveplate efficiency		
Material	[MgF_2][8]	MgF_2
transmission at 1550 Å	0.49[d]	0.78
transmission at 2800 Å	0.88[d]	TBD
polarization at 1550 Å	0.50 (225° retarder)	1.00 (630° retarder)
polarization at 2800 Å	0.89 (109° retarder)	0.72 (302° retarder)
Analyzer efficiency		
Description	Four mirror analyzer[9] optimized for 155nm	Double Wollaston
transmission at 1550 Å	0.12	0.55
transmission at 2800 Å	0.08	0.93
polarization at 1550 Å	1.0 (Brewsters angle)	1.0
polarization at 2800 Å	0.97	1.0
Spectrograph efficiency		
Description	Grating[11] and 2 Aluminum mirror[10] reflections	Spherical variable line spacing grating
reflectance at 1550 Å	0.21	TBD
reflectance at 2800 Å	0.13	TBD
polarization at 1550 Å(UVSP)[c]	0.40	TBD
polarization at 2800 Å(UVSP)[c]	0.49	TBD

a. Support structure not included. Therefore, the collecting area is the maximum possible**.**
b. Relative reflectance measurements converted to reflectance assuming Aluminum[10] reflectance at 1550 Å = 0.78 and 2800 Å = 0.92.
c. UVSP grating polarization[12] at 1550 Å = -.63, at 2800 Å = +0.70. See section 3.2 for polarization efficiency discussion
d. Assumes two 1.5mm MgF2 plates from Heath reference[8].

concept by (1) replacing the Gregorian telescope with a Ritchey-Chretien (increasing collecting area), (2) replacing the Ebert spectrograph design with a SVLS grating to reduce the number of reflections in the spectrograph arm from 3 to 1 and (3) replacing the four mirror analyzer with a double Wollaston. Since the initial design concept was not concerned with a limited observing time, the waveplate design was optimized for 135 degree retardance so that it could make vector magnetic field measurements. The current waveplate has been optimized for I±V and I+Q polarization measurements. This will allow the UV magnetograph to measure the longitudinal magnetic field in both the CIV and the MgII lines, and to make exploratory measurements of the linear polarization of the MgII line in strong field regions. Table 2 compares the initial design concept with that of the current SUMI sounding rocket design. At 1550 Å the improvement in the throughput over the initial SUMI design is greater than a factor of 10. Further improvement is expected with the fabrication and testing of the SVLS grating.

5. SUMMARY

The current SUMI design offers a significant breakthrough in the measurement of the magnetic fields in the transition region and the upper chromosphere. Measurement of the magnetic field in this region is crucial to understanding the dynamic events that occur in the outer layers of the solar atmosphere. Most of the Zeeman-sensitive lines in this region of the solar atmosphere occur in the ultraviolet. The CIV lines at 1548 Å and 1550 Å and the MgII *h* and *k* lines near 2800 Å have been selected for the SUMI baseline design. The CIV lines are pushing current technology, since (1) the irradiance of the solar spectrum is approximately three orders of magnitude smaller for the CIV lines than the irradiance of MgII lines, and (2) the absorption of all birefringent crystals (MgF_2, sapphire and UV quartz) that work in the UV starts to increase rapidly at wavelengths below 1600 Å. Therefore, some of the polarization optics that are being developed in the SUMI technology program may be useful only in an orbital mission that can accommodate a larger primary and longer observing times. Their use in a sounding rocket program will be contingent upon the observing program and the radiometry of the final instrument package. Because of the high transmission and polarization efficiency, the double Wollaston is the leading candidate for the SUMI polarimeter. However, its selection is still dependent upon the spectrograph design and the mechanical interface requirements of the sounding rocket.

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